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INTERIM REPORT NO. 4

RESEARCH AND DEVELOPMENT
OF
CACHE MARKER SYSTEM

TSS-PRO-4

WASHINGTON

PHASE II: DEVELOPMENT OF ENGINEERING PROTOTYPE

Covering the Period

15 June 1953 to 15 August 1953

Contract No. [redacted]

50X1

23 September 1953

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## ABSTRACT

A portable Q-Meter detection system has been designed and is being constructed. It will use an aural indicator instead of the meter used in the original design. A rotating capacitor has been constructed using a clock motor in order to eliminate one small electrical motor and associated batteries. Some improvements have been made in the amplifier which give much higher gain. The driver oscillator has been changed from a Colpitts to a Hartley type with resultant simplification of band switching and better stability. The packaging of the detector system has been given consideration and the prototype will reflect some of our ideas on the eventual design. A study has been made of the batteries which should be used to power this equipment.

A crossed-coil system was built and tested with disappointing results. Work on this system was discontinued.

The design of coils and coil forms for transponders was finished. The proper type of wire has been determined. An intensive investigation of packaging for the transponders has continued. At present a glass fibre reinforced plastic shell seems the most promising. Experiments leading to a suitable shell are being conducted in cooperation with a local plastics firm. In addition, the consulting services of a polymer chemist are being arranged in order to study methods of potting the coils.



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## I. Q-Meter Detection System

The work on the Q-Meter detection system was continued with the objective of building a prototype model which would be self-contained and portable. Several changes have been made since the first model was tested in the field, and these will be described.

### 1. The Rotating Capacitor

The first model which was tested in the field contained a motor-driven rotating capacitor which was used to assure that the two tuned circuits in the detector tracked together while searching for the transponder.[1]

A clock motor has been built to drive the capacitor. This eliminates the need for extra battery power to drive an electric motor and also eliminates the electrical noise inherent in such a motor.

The two plates of the capacitor consist of two thin aluminum plates cut to form internal teeth in a ring. Variations in capacity are accomplished by rotating a thin circular aluminum plate between them which has a diameter of 1.5 inches and has 20 teeth. It is staked to a small shaft which is mounted in jewel bearings as shown in the exploded view, Figure 1.

A Semca eight-day traveler's clock was modified to drive the rotating plate by mounting it so that it is driven by the last gear in the clock train. The rotor shaft was mounted in balance jewels with adjustable cap jewels. The entire mechanism was mounted in a case made of methyl methacrylate. In future designs the case will be made or material more dimensionally stable. Also the hub of the rotor will be made of an insulating material.

1 Interim Report No. 3.

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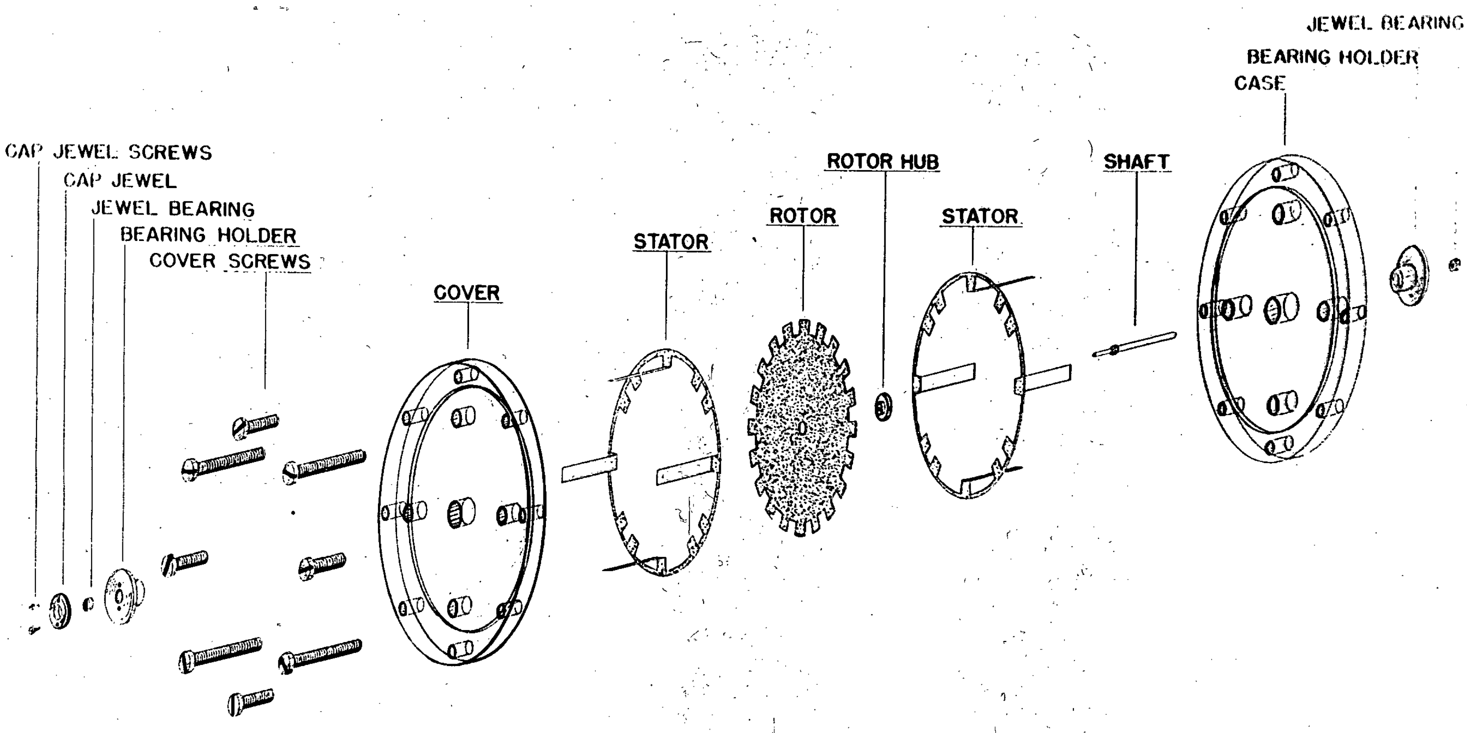


FIG. 1

EXPLODED VIEW - ROTATING CAPACITOR

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The clock work will drive the rotor for about one hour at approximately 300 RPM.

In a production program it would be feasible to make the capacitor plates by using printed circuit techniques. This would be economically and mechanically desirable.

2. Aural Indication

The Q-Meter detection system described in Interim Report No. 3 is being modified to provide an aural indication of the presence of the transponder. This is accomplished by utilizing the audio modulation of the RF produced by the rotating capacitor. A pair of high impedance telephones are connected across the crystal diode ahead of the RC filter. An audio signal of approximately 400 cycles is produced by the rotation of the capacitor. This frequency decreases slightly as the clock work runs down.

In operation the input bias level of the amplifier is kept constant and the oscillator drive is adjustable to produce an audible signal when no transponder is present. The maximum sensitivity is obtained when a signal is just barely heard in the phones. When a transponder is within the range of the detector a marked decrease will occur in the signal and a null will be produced. The effects of detector tuning and of the presence of a transpondor are easily observed by the aural indication.

3. Receiver Amplifier

The original Q-Meter incorporated a "window" amplifier in which the major amplification occurred at the frequency of the oscillator. An R-C coupling system was used in order to make the amplifier untuned. However at these frequencies such an amplifier is not very efficient. Measurements showed that the gain was only about 150. It was decided to convert to an



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audio frequency in the first stage and amplify only the audio signals. This has been accomplished by the circuit shown in Figure 2.

4. Oscillator

The investigation of oscillators which was reported in Interim Report No. 3 did not take into account two important factors:

a. The voltage which must be supplied to the load, and

b. The band switching problems which are encountered when providing for operation over a frequency band from 50 to 150 KC.

The oscillator supplies energy to a low resistance ~~when~~ which is paralleled by the fluctuating load of the series resonant circuit. In order to achieve frequency and amplitude stability it is necessary to make this load appear constant to the oscillator. In the Q-Meter this is accomplished by making the value of low resistance element so small that variations in the series resonant circuit impedance have little effect on the total load on the oscillator. A value of 0.27 ohm has been found effective for this purpose.

The complexity of the band switching circuits is affected by the type of oscillator circuit used, the range of the tuning capacitors and the width of the individual bands. A Colpitts oscillator requires a change in the series capacity divider (coupling) for each band in order to maintain stable oscillations and necessary output. The Clapp oscillator also uses a series capacity voltage divider. These changes in capacity add materially to the difficulty of tracking the tuned circuits in the detector. However the Hartley oscillator can be switched from one band to another with the least amount of difficulty. The detector now under construction





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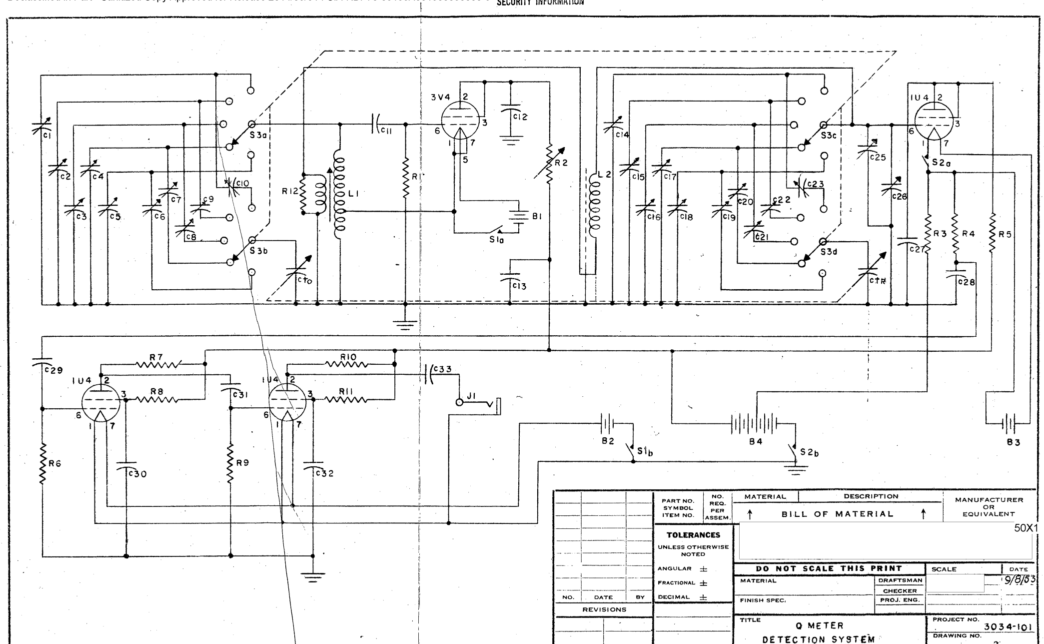


Figure 2.

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## PARTS LIST

$C_1$, $C_{10}$, $C_{14}$, $C_{23}$ - Arco #463 Trimmer Capacitor

$C_2$, $C_9$, $C_{15}$, $C_{22}$ - Arco #466 Trimmer Capacitor

$C_3$, $C_4$, $C_5$, $C_6$, $C_7$, $C_8$, $C_{16}$, $C_{17}$, $C_{18}$, $C_{19}$, $C_{20}$, -Arco #469 Trimmer Capacitor
$C_{21}$, -Arco #469 Trimmer Capacitor

$C_{11}$ - 100 uuf Silver Mica
$C_{12}$, $C_{13}$ - 1.0 uf @ 400V Paper
$C_{25}$ 4uuf to 11 uuf Var. Air Trimmer
$C_{26}$ Special Motor Driven Capacitor
$C_{27}$, $C_{28}$, $C_{30}$, $C_{32}$, $C_{33}$ - 0.02 uf
$C_{29}$, $C_{31}$ - 0.05 uf
Cto Osc. Tuning
Ctr Rec. Tuning

$R_1$ - 150 K
$R_2$ - 10,000 ohm var.
$R_3$, $R_4$, $R_5$ - 10,000
$R_6$, $R_8$, $R_9$, $R_{11}$ - 1 Meg.
$R_7$, $R_{10}$ - 470 K
$R_{12}$ - 0.27 ohm

$B_1$, $B_2$, $B_3$ - 1.5 V Battery
$B_4$ - 135 V Battery

$J_1$ open circuit jack

Note: Band Switch is Shown in Position 2



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will use a Hartley oscillator and the range of each band is being made as large as the tuning capacitors will permit. It may be necessary to reduce the band width of each range in order to accomplish the required accuracy of tracking.

5. Configuration of the Detector System

The two principal components of the detector are the detection coil and the box which contains the electronic circuitry including the batteries. When in use the box will be fastened to the waist of the operator. The detector coil may then either be suspended at about waist height and parallel to the ground or worn around the waist with the body of the operator inside the coil. The latter arrangement would be more desirable since the coil could be worn under a garment.

It has been found that the Q of the detector coil does not change appreciably when worn around the waist. However the changes in distributed capacity are serious. An investigation will be made to see whether some kind of shielding can be devised which will eliminate these capacity effects.

6. Packaging of Detection System

The design of the detection system should have the following objectives:

a. Location of the controls for ease of operation,

b. Arrangement of the components consistent with objective a in order to occupy the least space, and

c. Arrangement consistent with objectives a and b which will make fabrication and servicing as simple as possible.



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By fastening the box containing the electronic components to the waist of the operator both hands are freed to operate the controls. The main tuning control and band switch will be mounted on top of the box. The amplitude and fine tracking controls will come out through the sides. Since the latter two are adjusted by ear, it is unnecessary to see them. The present model is being built with these objectives in mind. Details will be given in the next Interim Report.

7. Power Supply

There are a number of different kinds of batteries that can be used to supply the power needed to operate the detection system. In choosing the kind of battery that is to be used, consideration must be given to weight, size, dependability, operation at low temperatures and cost.

The model of the detection system which is presently being built will use dry batteries which are readily available. It would not be difficult to change to another kind of battery if the same voltages and currents are available for the same space.

There are batteries available, manufactured by the Burgess Battery Company, of the silver chloride-magnesium or cuprous chloride-magnesium construction which are water activated batteries. In the dry state, they have a very long shelf life. They become activated by putting them in water for one or two minutes. The water need not be distilled. Tap water, lake or sea water will serve equally well. These batteries must be activated above the freezing point of water, but they will operate at ambient temperatures from $-60^{\circ}F$ to $+150^{\circ}F$. Compared with dry batteries of equivalent electrical characteristics, the water activated batteries are lighter and occupy less volume.

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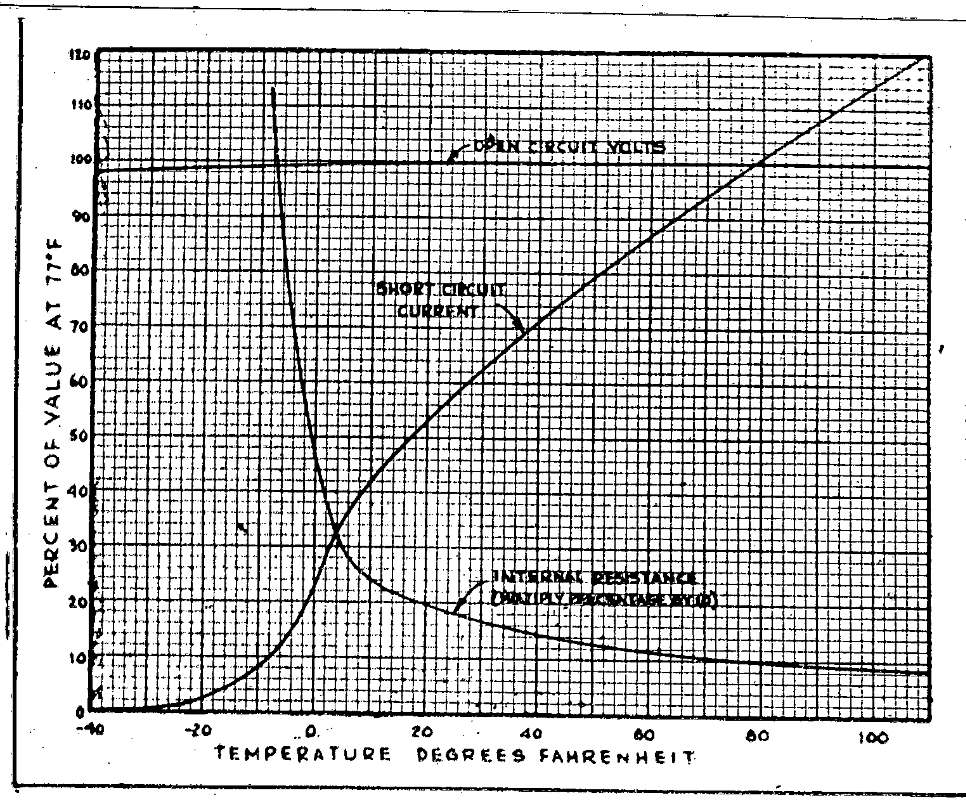


Effects of Temperature on Dry Battery Performance.

Figure 3.

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The effects of temperature on dry batteries are given in a U. S. Department of Commerce publication, LC965, 11/15/49, entitled "Electrical Characteristics of Dry Cells and Batteries (Leclanché Type)". The important factors are storage and operation under adverse temperatures. Storage at above normal temperatures is detrimental to the operation of dry batteries. Low temperature storage preserves the life of the battery. The effects of temperature on the performance of dry batteries is shown in Figure 3. The internal resistance of the battery as a function of temperature considered in conjunction with the load requirements determines how low in ambient temperature satisfactory operation will still occur. The open circuit voltage remains substantially the same from -40°F to + 110°F. The capacity of a dry cell varies with temperature being 27 per cent at 0°F as compared to that obtained at 70°F.

It can be concluded that dry batteries which are fresh or have been properly stored will work satisfactorily at ambient temperatures of 0°F or with a shorter life (about 10 per cent as compared to 70°F) at -10°F. If it is anticipated that operation of the detection system will be needed below this temperature or that obtaining fresh batteries is a problem, then either water activated or mercury batteries should be used.





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## II. Crossed-Coils System

A Detectron Model 711 Metal Detector was purchased to determine whether the conventional metal detector could be used to detect a transponder. This metal detector is similar to the crossed-coil system except that it operates at only one frequency. It consists of two coils, mutually perpendicular. One is the oscillator coil and the other is the receiver pick up coil. The oscillator is of the Hartley type, operating at 100 KC. The receiver consists of a tuned RF amplifier followed by a detector and three stages of audio. The detector consists of a mixer stage with a local oscillator to give a difference frequency which is audible. The two coils are each shielded by a rectangular box whose sides are metal except for one side which is wood. The top and bottom are made of masonite. The control is adjusted for a null by balancing out stray capacitive coupling between oscillator and receiver through the ground and surrounding objects. The control changes the orientation of the receiver coil, which is pivoted about two points. The position of this adjustment for a null changes with the position of the detector with respect to its surroundings.

A transponder was tuned to the same frequency as the detection system in order to determine the ability of the metal detector as a transponder detector. It was found that the transponder could be detected at a maximum distance of ten feet.

Efforts were made to build a variable frequency crossed-coils detection system. The only possible advantage this system would have over the Q-Meter detection system is increased sensitivity.



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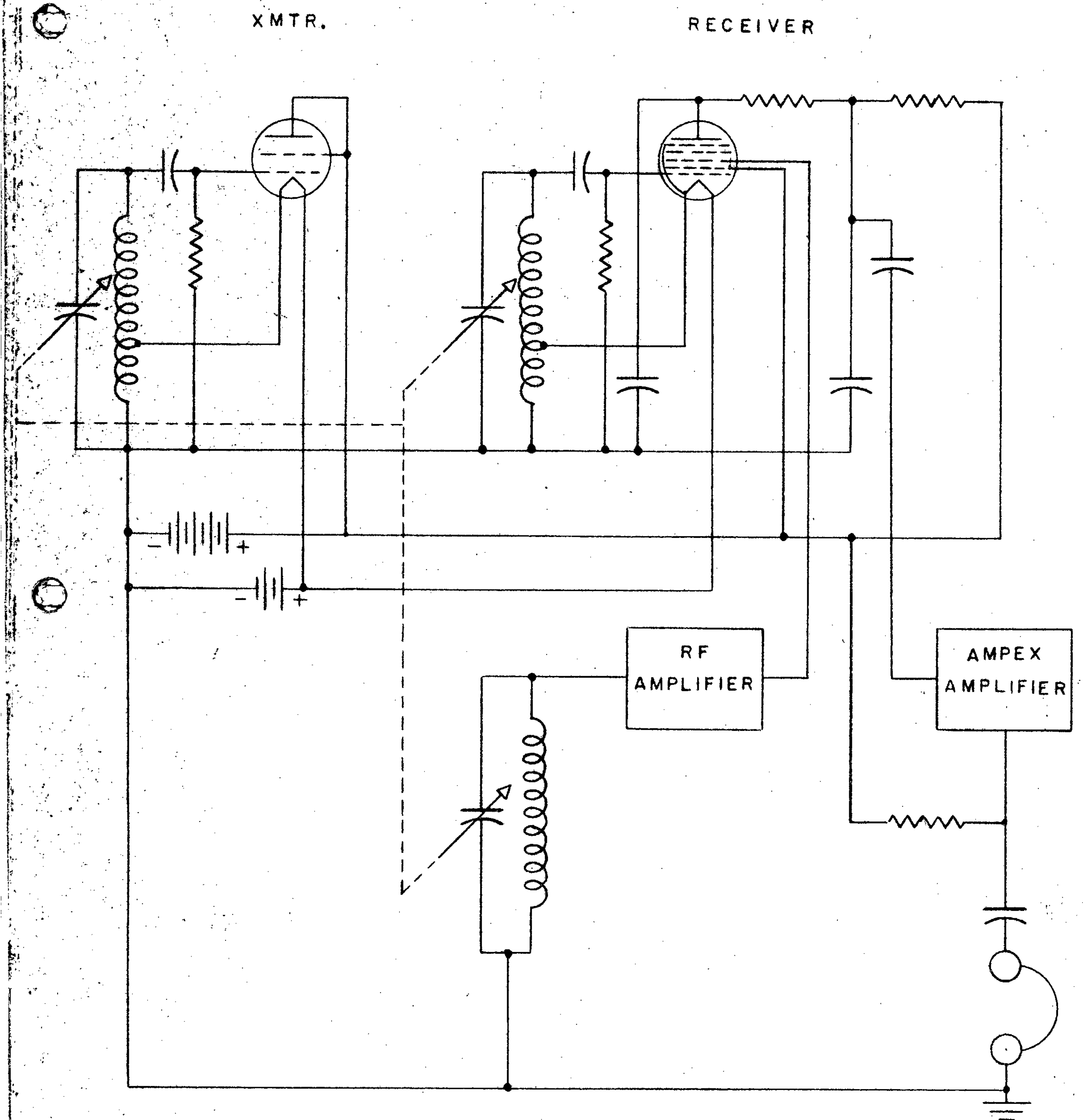


Fig. 4 A Crossed Coil Detection System


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The circuit shown in Figure 4 was built up as a crossed-coil system. The principle of operation is as follows. The oscillator in the receiver is detuned from the transmitter and receiver coil by an audio frequency. Thus, when a transponder is present, the received signal from this source is mixed with the receiver oscillator signal to produce an audio output. The filter network in the plate of the converter then allows only the difference frequency to pass on to an audio amplifier.

In this first version, several difficulties were encountered. The most serious were that the receiver oscillator coupled or radiated into the receiver coil, and the transmitter apparently interacted with the receiver oscillator because of the nearness of the two frequencies. The overall effect was to produce a poor null with no transponder present and poor sensitivity when a transponder was present. With the system operating as shown it was possible to detect a transponder of a maximum of about three feet. With the addition of an amplifier after the receiver coil, the sensitivity was increased to approximately six feet. However, this modification did not completely eliminate the poor null.

Another difficulty encountered was the capacity effect. The added capacity present due to a person standing near the transmit and receive coils shifted the frequency with each movement of the person. In an effort to eliminate this effect an electrostatic shield was placed around the transmitter coil. This greatly improved the operation; but, here again, the effect was only reduced, not eliminated.

In view of the limitations of this type of circuit, particularly the problems encountered because of the nearness of the transmitter frequency to the receiver oscillator frequency, it was decided to construct a superhetrodyne receiver. Such a receiver was constructed employing a 175 KC IF and a BFO.

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The front end of this receiver proved to be very insensitive. The first detector consisted of a 1R5 and was preceeded by two stages of RF amplification using 1U4's. In an effort to avoid a tracking problem the RF amplifiers were made RC stages. However the gain is limited to less than ten per stage over the frequency range 50-150 KC because of the large input and output capacities. The real difficulty, however, was found to exist in the first detector. With a relatively large signal present on the signal grid of the converter tube, indicating the presence of a transponder, a small and very broad signal exists in the plate circuit of this tube. All attempts to correct this condition by changing the parameters in the converter stage have been unsuccessful.

No further work has been carried out on this circuit because of the accelerated pace established on the Q-Meter detection system.



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## III. Transponders

### 1. Coil Forms

The design of the coil form has been based on the following factors. The outside dimension has been determined by the requirement that the transponder must fit into an air drop container whose inside diameter is slightly larger than fifteen inches. The shape of the coil form, consisting of a rim with three rows of pegs placed around the periphery, is one which produces a high Q coil with the wire distributed to give a high mutual inductance with respect to the detection coil. An experiment comparing the Q of a coil of the design described above with a coil of single layer solenoid type construction of comparable diameter, using the same number of turns of the same wire, gave a Q of 400 as compared to the 15 obtained for the single layer coil.

Measurements were made to determine what effect staggering the pegs would have on the Q of the transponder. Making the coil form in this way reduces the spacing between turns of adjacent pie sections of the coil. No difference is Q or inductance was observed. It did make winding the coil a more difficult process.

To simplify the molding of this form, it was decided to make the coil form out of three identical pieces. This requires a mold without any under cuts and keeps the cost of the metal dies to a minimum. The individual pieces of the coil form (see Figure 5) are supplied with dowel extensions and holes which permit easy assembly. The material that has been suggested by the molding companies is styrene, which has good electrical and mechanical properties, and which allows easy cementing of the pieces together.



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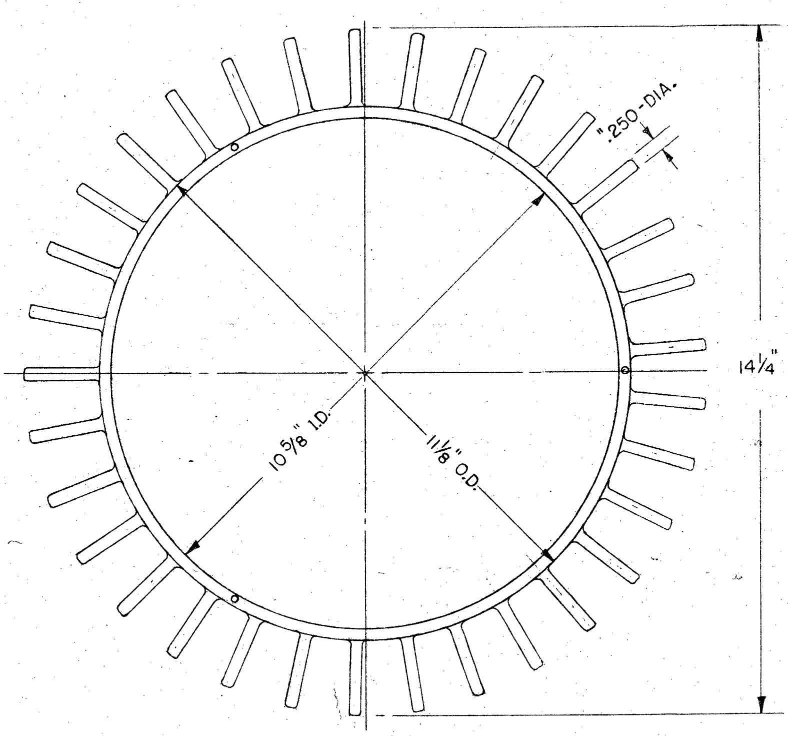


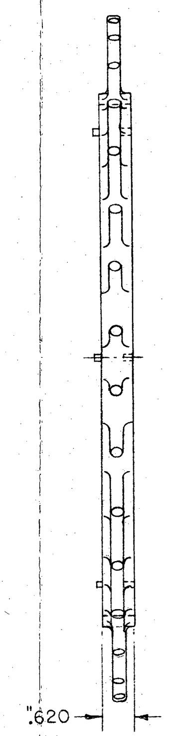


COIL FORM

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The replies to our inquiries for making the metal dies and molding the coil forms quote a price range for the metal mold for injection molding of \$990 to \$4625 with an estimated time for completion of 12 to 14 weeks. The prices per molding for quantities of 1000 vary from \$0.359 to \$0.75, and in quantities of 10,000 from \$0.287 to \$0.65.

2. Wire

Measurements have been performed to determine the properties of transponders made of coils whose outside diameter is 14½ inches. Four transponders were measured, each wound with a different kind of wire. The number of turns was determined by the wire diameter, the maximum possible number of turns being used in each case. The different wires used are as follows:

No. 1 - 105 turns of litz wire consisting of 50 strands of No. 38 where the strands are merely bunched together.

No. 2 - 60 turns of litz wire consisting of 25 strands of No. 30 where the individual strands are braided on a glass fibre core.

No. 3 - 90 turns of litz wire consisting of 64 strands of No. 38 where 8 strands are braided together to form a cable and then 8 such cables are braided together.

No. 4 - 99 turns of No. 18 solid wire formvar insulated.

The wire for the first two coils was supplied by New England Electrical Works. The wire for the third coil was supplied by Belden. The first coil that was wound for No. 3 transponder had only a Q of about

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100. Measurement of the DC resistance indicated a value four times as high as the calculated value and measurement for continuity indicated 75 per cent of the strands were broken. Careful selection of the 9000 feet of wire from Belden resulted in a piece long enough to wind a No. 3 coil which was free of defects.

This incident points out the difficulty in braiding wires as fine as No. 38. This difficulty has not been encountered with litz wire made of No. 38 where the strands have been merely laid together and wrapped. The New England Electrical Works has informed us that No. 38 could not be braided without breakage on his machines. On the other hand, the fabrication of litz wire using No. 30 braided is no difficult problem.

The Q of each coil was measured as a function of frequency. The results of these measurements are displayed in Figure 6. There is a dip which occurs at 120 KC which has been indicated only by the experimental points. The smooth curves drawn ignore these points. The cause for this dip has been attributed to the NSS transmitter at Annapolis which operates at 123 KC.

In order to determine the relative merit of these coils, i.e. their detectability, the Boonton Q-Meter and the coil which was designed for the detection system was used. The Boonton Q-Meter was adjusted to measure the Q of the detection coil and the transponder coil was then tuned through resonance and the change in Q was observed. The transponder coil and the detection coil were maintained parallel with their axes of symmetry collinear. Readings were taken of the change in Q for frequencies 10 KC apart from 50 to 150 KC. The results are shown in Figure 7.

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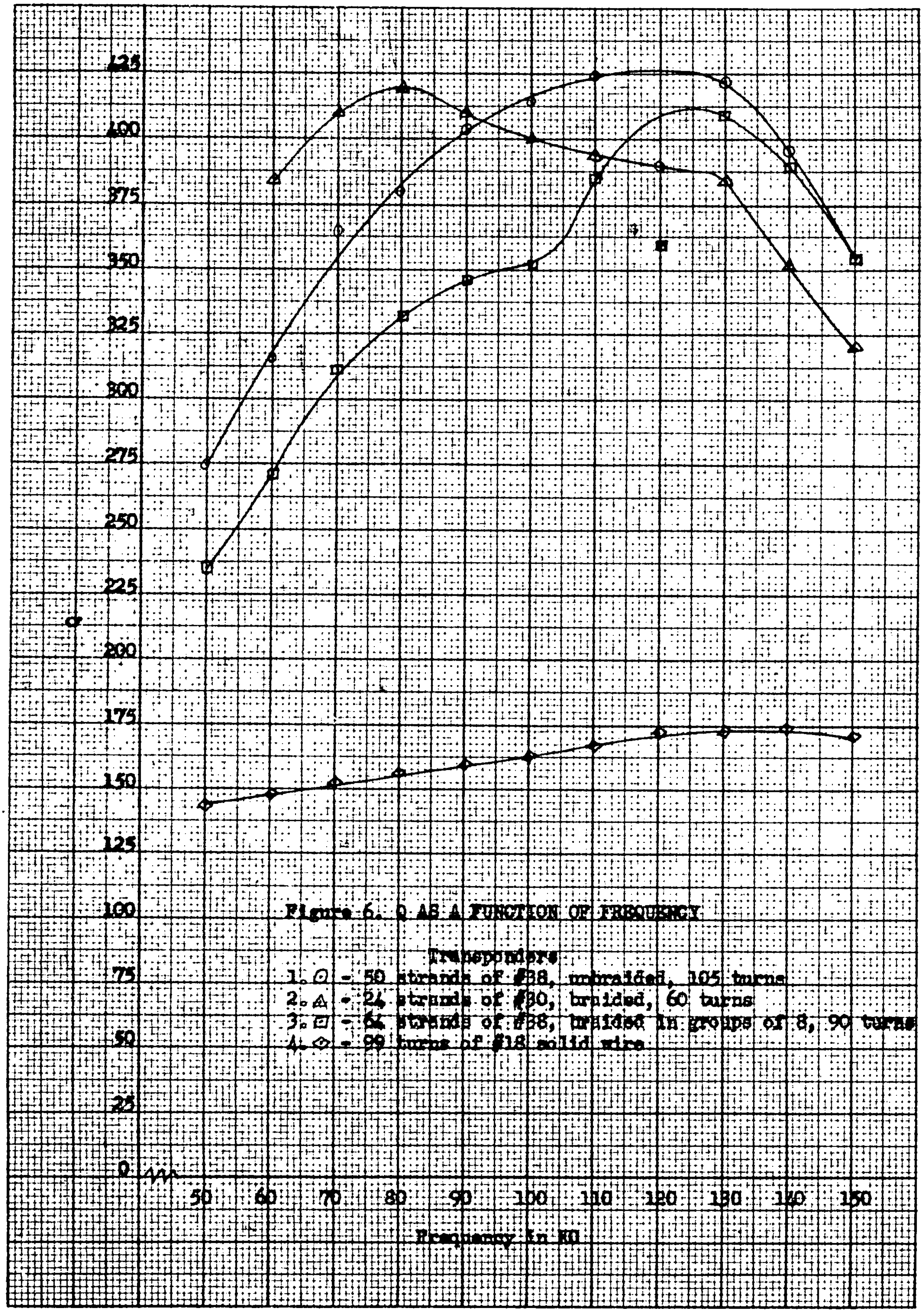


Figure 6. Q AS A FUNCTION OF FREQUENCY

Transponders

1. ○ - 50 strands of #38, unbraided, 105 turns
2. △ - 24 strands of #30, braided, 60 turns
3. □ - 64 strands of #38, braided in groups of 8, 90 turns
4. ◇ - 99 turns of #18 solid wire





No. 911-18, 20 x 20 to 1"
Each 10th line heavy, each 5th line grounded
The A. Lietz Co., San Francisco
Made in U. S. A.

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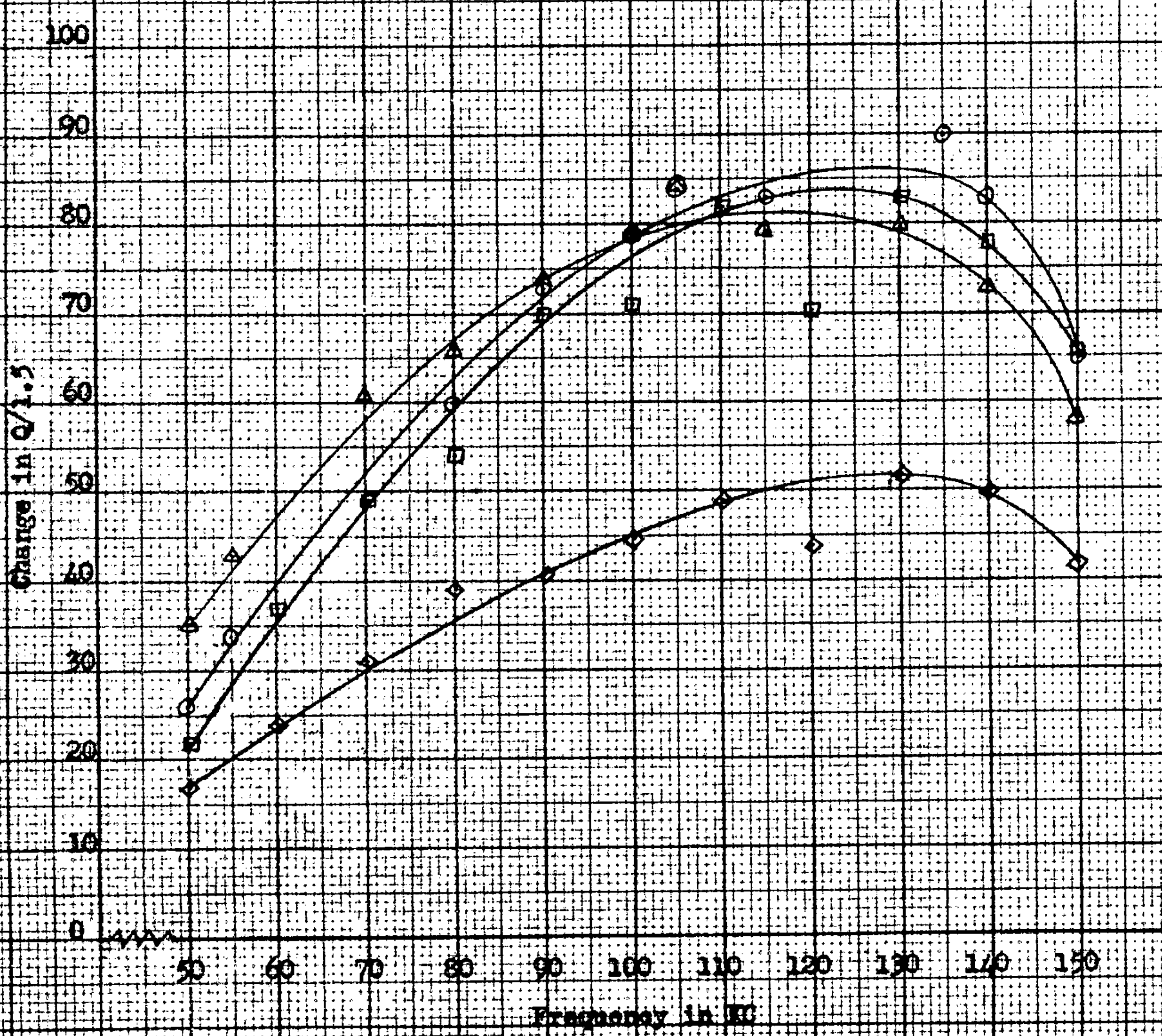
Figure 7. TRANSPONDER RESPONSE CHARACTERISTICS

All measurements made at four feet

Transponders
1. ○ - 50 strands of #35, unbraided, 105 turns
2. △ - 24 strands of #30, braided, 60 turns
3. □ - 64 strands of #38, braided in groups of 8, 90 turns
4. ◇ - 99 turns of #18 solid wire




No. 911-18, 20 x 20 to 1"
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### 3. Packaging

There appear to be two main avenues of approach to the problem of packaging: the shell type structure, or potting in a casting resin.

#### Shell Type Structure

This method of packaging consists of placing the tuned circuit inside of a case made of a material which has good mechanical and electrical properties. It was mentioned in Interim Report No. 3 that the use of a foam-in-place plastic was being considered as a core. Lock foam appears to have suitable electrical properties, but it is not only expensive both in initial cost and the cost of handling it in the production of transponders, but it is believed to be unnecessary in that the glass fiber reinforced plastics that are being considered for the shell have more than sufficient mechanical strength.

The design of the shell that we are considering is shown in Figure 8. The major problem in the design of the transponder case is that of the joints or seals around the inside and outside diameter. They must be of such a nature that accidental dropping will not result in large forces tending to pry them apart. This would be the case if the same lip for sealing which is used on the inside diameter was used on the outside diameter. The increase in diameter of the case, beyond that of the coil, is another objection to this type of joint for the ouside diameter. The seal for the outside diameter consists of a butt joint with an overlapping strip around the outer circumference. This allows the use of symetrical pieces for the case which keeps the cost of tooling down. If very large quantities of transponders are anticipated, then there would be advantages to making the pieces unsymetrical, obtaining an overlapping joint without the use of a sealing band.



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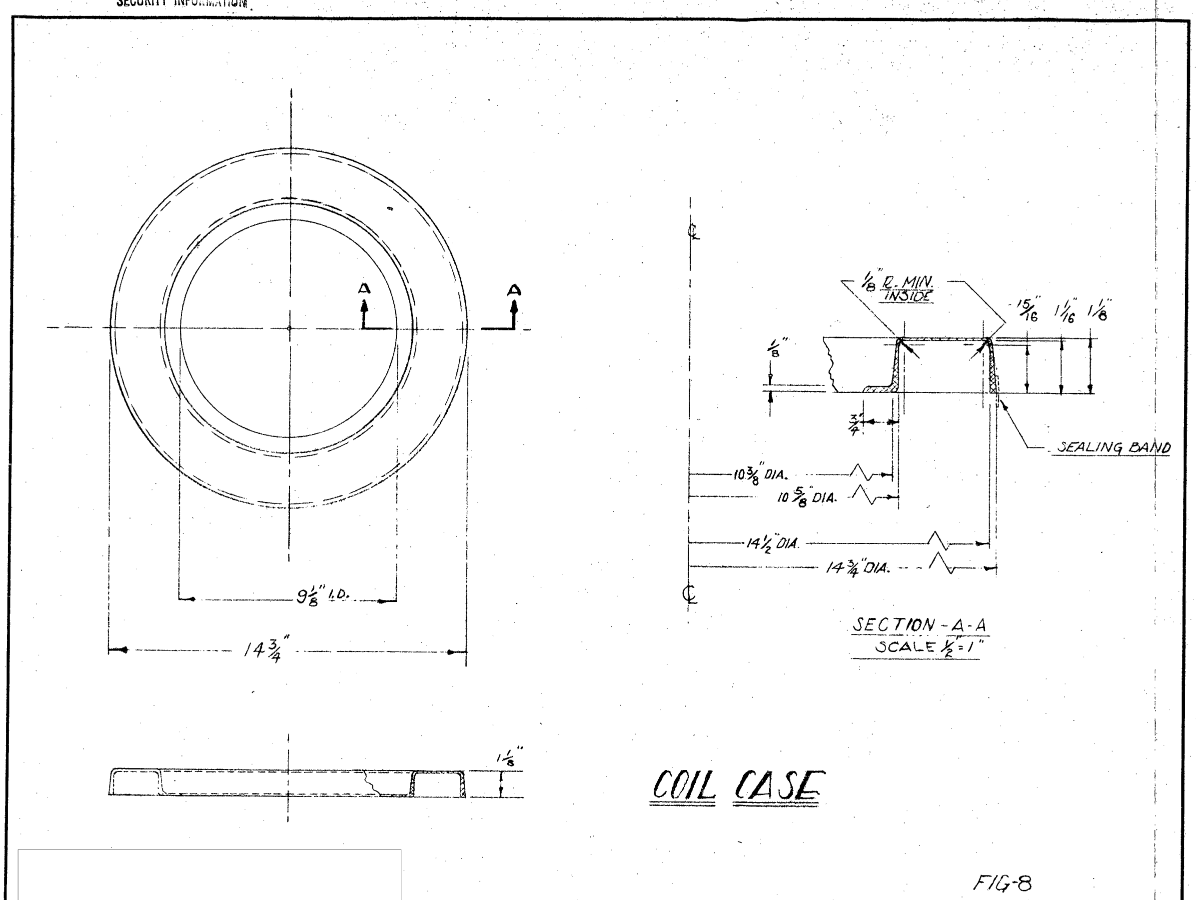


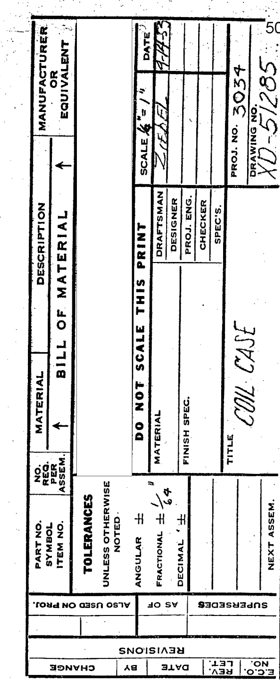


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Inquiries have been sent out to a number of companies which make glass fiber reinforced plastic molding. Thus far, only one company has been heard from: the Apex Electrical Manufacturing Company. They sent a representative to us to discuss our problem. He told us that the cost of the dies for matched metal molding would be approximately $3000 and the cost per half shell about $2 in lots of 1000, which would be sufficient to make 500 transponders.

In order to test some transponders using this type of structure, the W. R. Chance Corporation in Arlington, Virginia, was contacted. They make fiber glass reinforced plastic boats as well as containers for electronic equipment for the Navy, using hand layup and vacuum bag techniques. The results of the tests which will be made in transponders encased in shells made by these facilities will determine the course taken with regard to large production facilities.

Potting

This method of packaging consists of casting the tuned circuit in a solid block of material. The material used must have the necessary electrical properties so that the potting process does not substantially alter the detectability of the tuned circuit. The mechanical properties must be such as to provide protection from any of the environmental conditions which exist during storage, transportation and burial. The requirements for low dielectric losses appear to be more stringent for the material used for solid casting than for the shell structure because of the close physical contact of the potting material with the wire of the coil.





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One of the materials that we have considered has been Cerese AAA wax. Our experience has indicated that the electrical properties are well suited for our application. At room temperature the observed mechanical properties are sufficient to withstand rough handling such as accidental dropping. Measurements were made to determine what would happen at high and low temperatures.

A one inch cube sample of the wax was placed in a water bath under 6 psi. The temperature of the bath was raised until deformation of the wax sample occurred. The wax sample deformed at 168.8°F. No deformation occurred below this temperature. A similar sample was placed in a refrigerator reducing its temperature to 18°F. The sample was immediately placed in a vice which was tightened to the point where the sample was completely deformed. This occurred without fracture, indicating the material remained tough at this temperature. A transponder cast in the wax dropped from four feet to a concrete deck cracked when it landed on edge but remained intact when it landed flat.

Another one of the materials which has been considered is the AN-5 casting resin. A small sample was cured to become familar with handling this material. It cured at 50°C in 48 hours. The sample was found to be quite brittle in that it fractured when hit with a hammer. A transponder was cast in this resin, requiring about four days at 50°C to completely cure. The potted transponder was tested electrically, and it appears to change little due to the potting. No mechanical tests have been made; but from the experience with the transponder cast in wax, it is expected that it will not withstand a four foot drop without fracture.

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In order to investigate thoroughly the potting technique as a means of packaging, a polymer chemist is being hired as a consultant. He is employed by the Atlantic Research Corporation.

Program for next interval.

1. The work on construction of the new model of the Q-Meter detection system will continue.

2. The work on packaging of the transponders will continue. It is expected that transponders packaged using the shell structure will be ready for tests during this period.

3. Experiments will be performed to determine whether the detector coil can be effectively shielded so that it can be worn around the waist of the operator.

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